The second figure shows the detector circuit and thermal isolator mounted to its titanium base and flexible cable assembly. Signals are conveyed via flexible printed circuits to connectors that interface the detectors thermally and electrically to a low-thermal-conductivity cable bundle (not shown) which is part of the science instrument assembly.

Ames personnel have been fully matricized into the Telescope Readout Electronics Group of the GPB Project. Significant technical contributions have been made in the areas of cryogenic characterization of electronic components, circuit design, standardization, manufacture, detector circuit acceptance testing, flexible cable design and manufacturing, thermal isolator design and testing, optical calibration, quality assurance, detector package assembly, and acceptance testing.

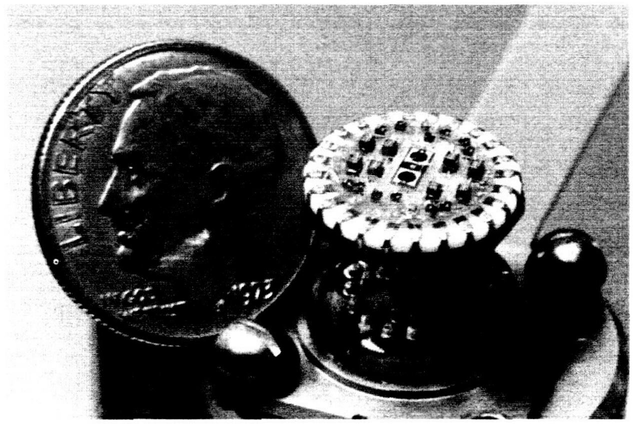

Fig. 2. Guide-star detector circuit and thermal isolator.

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Modeling of Steady Secondary Flows in Pulse Tube Cryocoolers

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A linearized solution for describing steady secondary flows generated by periodic compression and expansion of a gas in a tube has been developed and verified. The small-amplitude series expansion in the inverse Strouhal number at the anelastic limit is applied to the two-dimensional axisymmetric equations for mass, momentum, and energy conservation for an ideal gas. The solution is calculated to higher-order for understanding mass and enthalpy streaming. This work is useful for predicting the streaming losses that are present in pulse tube cryocoolers.

The ordered equations show that the zeroth-, first-, and second-order equations are coupled through the zeroth-order temperature. An analytic solution is obtained in the strong temperature limit where the zeroth-order temperature is constant. The solution shows that periodic heat transfer between the gas and tube, characterized by the complex Nusselt number, is independent of the axial-velocity boundary conditions and the Fourier number. Steady velocities increase linearly for small Valensi numbers and can be of order 1 for a large Valensi number. Decreasing heat transfer between the gas and the tube decreases steady velocities for systems in which nonzero velocity boundary conditions exist at each end of the tube, such as for orifice pulse tubes. For systems in which one end of the tube is closed, such as for basic pulse tubes, increasing heat transfer between the gas and tube decreases steady velocities. The model predicts that a conversion of steady work flow to heat flow occurs whenever temperature, velocity, or phase-angle gradients are present. Additionally, steady enthalpy flows are reduced by heat transfer and are scaled by the Prandtl number times the Valensi number.

Particle velocities from a smoke-wire experiment were compared to model predictions for an orifice pulse-tube configured system (see figure). Mass-streaming and flow reversal between the centerline and diffusion layers of the gas were observed, and velocities were measured. The theory predicted the

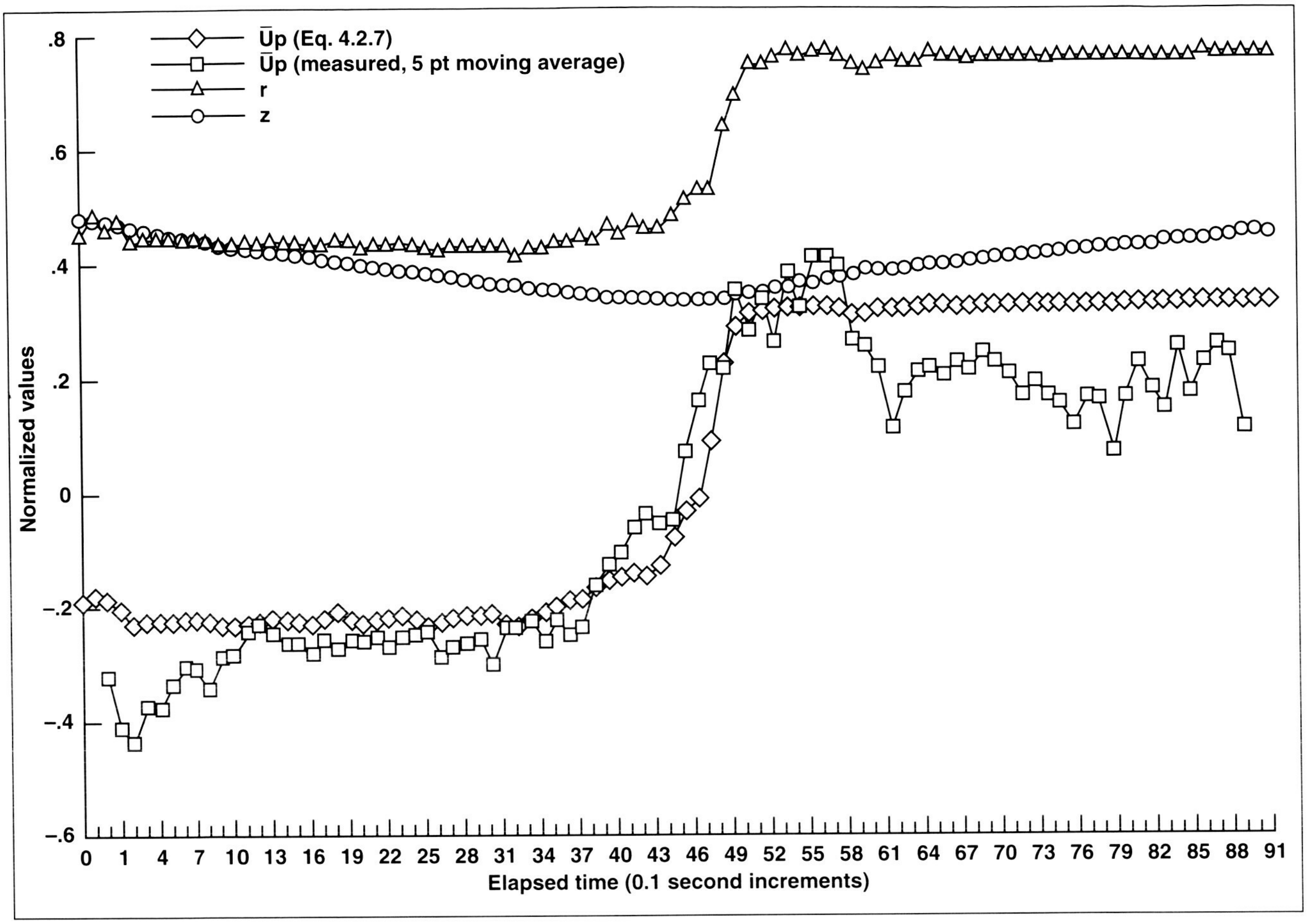

Fig. 1. A comparison of measured and predicted higher-order steady secondary streaming particle velocities in oscillating compressible flow. Data were obtained for a Valensi number of 68 and a velocity phase angle of 90 degrees. The measured velocities were obtained from smoke-visualization experiments.

speed and direction of the mass-streaming, and the locations where the flow reversed. The results indicate that the theory is valid for pulse tubes and that it can be used to solve for the zeroth-order temperature, to compute enthalpy flows, and to determine losses associated with steady secondary streaming. The theory can be used to minimize secondary flow losses when designing pulse tube coolers.

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